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APPLICATION OF RAPID HEAT TREATING TO CANNON TUBES

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER WEAPON SYSTEMS LABORATORY
BENÉT WEAPONS LABORATORY
WATERVLIET, N. Y. 12189

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In order to demonstrate the feasibility of shortened heat treatment cycles for gun tubes, eight forgings (four 105mm M68 and four 155mm M185) were subjected to reduced austenitizing and tempering times. Austenitizing time was held to 30 minutes at temperature as measured by thermocouples. Quenching was accomplished by either vertical immersion, horizontal immersion or horizontal spray. The results showed that accepted mechanical properties

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could be attained with these shortened cycles. However, the shortened cycles must be established for a particular component with consideration for material variation, especially chemical segregation, which seriously affects transformation behavior. Nevertheless, in view of the present and future costs of firing heat treat furnaces and the potential increases in production capacity, reduced heating times can be highly significant.

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DEPARTMENT OF THE ARMY
U.S. ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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DRDAR-LCB-SE

Project No: 6767236

Project Title: MM&T: Application of Rapid Heat Treating to Cannon Tubes

Statement of the Problem: The present industrial heat treating practices for alloy steels generally require soaking times of a minimum of one (1) hour per inch thickness. This practice is used on gun tube forgings purchased from private industry. Traditionally, such criteria were established to compensate for poorly designed and controlled furnaces, along with inadequate temperature sensing systems. Also, long soak times were supposed to homogenize alloys. However, the typical austenitizing temperatures for low alloy steels, e.g., 1500-1600°F (815-871°C) readily disperse the major hardening elements and actually contribute little to homogenizing alloy segregation[1-2]. Thermal treatment in excess of 2000°F (1093°C) for extended periods of time is necessary to effect homogenization of segregated alloying elements, viz., Cr, Ni, Mo.

Therefore, commercially heat treated gun tubes and many other heavy ordnance components are subjected to thermal soaking treatments in excess of a fully austenitized condition. Such treatments not only increase the time and labor associated with production, but increase the consumption of fuel required to fire the furnaces. The net result, therefore, is a more expensive product.

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1. Aaron, H.B. and Kotler, G.R., Met. Trans., 2 393 (1971).
2. Griffen, R.B. and Pepe, J., Wvt Ars. Tech. Report, WVT-7252, Oct. 72.

This project was accomplished as part of the US Army Manufacturing Technology program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques and equipment for use in production of Army materiel.

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to Cannon Tubes

Background and Introduction: Traditionally, long soak times are commonly used by the heat treatment industry to "homogenize" an alloy prior to quenching. For instance, a typical heat treatment of a 105mm M68 forging by a commercial vendor is as follows:

> "Heated to 1750°F in 10 hrs., held 10 hrs., air cooled 8 hrs., reheated to 1525°F in 10 hrs., held 10 hrs., water quenched 13 minutes. Charged into tempering furnace at 500°F. Raised temperature to 1045°F on muzzle and 1055°F on breech in 10 hrs., held 12 hrs., water cooled".

This particular treatment takes approximately 70 hours. Also, some vendors perform a double tempering operation which would further increase the total heat treating time. Several investigations have shown that double tempering of the 43XX series steels is of uncertain benefits[3-6] and a recent study of gun steel concludes that the tempering time for cannon tubes can be shortened considerably[7].

Currently, the furnaces and temperature measuring systems commercially available are more efficient and precise than those used in the past. Therefore, it is possible to accurately chart the temperature time history for a gun tube being heat treated. Once the austenitizing temperature is achieved at the mid-radius, it should only be necessary to hold the forging at temperature until transformation is complete. This procedure will also minimize austenitic grain growth which has been associated with decreased mechanical properties, especially impact toughness.

Approach to the Problem: Eight (8) rotary forged gun tubes were prepared for this study by placing thermocouples (TC) in the breech end (thickest section) as follows:

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3. Whelan, Met. Sci Journal, 3 95, (1969)
4. Kaufman, Radcliffe, and Cohen, "Decomposition of Austenite by Diffusional Processes", Interscience Pub., NY, 1962.
5. James and Leak, Phil. Mag., 12, 49, (1965).
6. Bowen and Leak, Met Trans., 1, 1965 (1970).
7. Heiser, F., Heat Treating Gun Steel, Wvt Technical Report ARLCB-TR-78006, March 1978.

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"Measuring from the breech face, a distance equal to the wall thickness was marked. At this location, a 1/4" diameter hole was drilled from the OD to a depth of 1/2 the wall thickness. The tip of the Type K thermocouple was inserted into the hole to the midwall position and secured. During the heating, the tubes were oriented so that the TC's were in the 12 o'clock position".

During austenitizing, Forgings No. 6047 and No. 6006 (horizontal immersion quench) were charged into a furnace preheated to 1200°F, and brought up to temperature. The temperature was then raised to 1550°F as measured by the TC readings. (Appendix I). The tubes were held approximately 30 minutes, then quenched. The remaining six (6) forgings were charged into a furnace preheated to 500°F. The temperature was raised 120°F/hr. to 1550°F and the tubes individually held for 30 minutes. Quenching was accomplished by vertical immersion or horizontal spray.

Tempering was performed at 1050°F as measured by TC, for 4 hours (at temperature) followed by air cooling of #6047 and #6006, and water cooling (20 minutes) the remaining six forgings.

The heat treated tubes were sampled in four locations for a total of 16 tensile and 16 Charpy impact specimens per tube. This plan is illustrated in Figure 1.

Results and Discussion: The results of mechanical testing on the heat treated forgings are tabulated in Appendix II. These data are also summarized in Tables 1-3, according to the type of quenching procedure. In the case of Vertical Immersion, which represents the conventional mode of quenching gun tubes, several values of yield strength exceeded the 160-180 ksi requirement*. In fact, the yield strengths were generally on the high side of the required range. This behavior is illustrated in Figures 2-5 which show the average value along with the maximum and minimum values within a disk. A condition of slightly high yield strength in this material indicates that the tempering temperature was low and this parameter can be easily adjusted to achieve the desired range. However, one disk (07M) in Forging No. 6007 exhibited low yield strength values and relatively high scatter (153-175 ksi). This particular behavior is also accompanied by low Charpy impact values (Figure 5). A metallographic examination of these specimens revealed a microstructure of tempered martensite and areas of ferrite plus carbide with a banded or laminate appearance (Figure 6). The carbide phase in this constituent

*This requirement taken from the Cannon Tube Forging Spec. (MIL-S-46119A) was used as a guideline in heat treating.

exhibits both rod-like and discontinuous particle morphologies. These features are reminiscent of a pearlitic microstructure with alternate lamellae of ferrite and iron carbide. Under the circumstances of this experiment, there is a possibility that the prior microstructure was not completely transformed during austenitization. This circumstance would be affected by chemical segregation of the steel and the heat treating parameters viz., temperature, time, vendor's practice, etc.

Also, the % RA in Forging No. 6004 displayed a noticeable variation within discs (Figure 4) and several values were below the required minimum of 25%. Variation in this property can be influenced by material variation such as chemical segregation, nonmetallic inclusions, porosity, etc. Unfortunately, the variation associated with heat treatment alone, cannot be differentiated in this experiment. Thus the observed variation is the total variance due to real material variation, variations in heat treatment factors and experimental error.

With the exception of three discs, the Charpy impact response in these vertical quenched forgings, was acceptable and exhibited relatively little variation. Typically, these properties would benefit from a decrease in yield strength level unless a serious material problem other than heat treatment, existed.

Two forgings, a 105mm M68 (No. 6047) and a 155mm M185 (No. 6006) were horizontally immersed during quenching. This data is summarized in Table 2 and displayed in Figures 7 and 8. Again, the yield strength values tended to be high, but disc BB in Forging No. 6047 exhibited relatively low Charpy impact in one specimen (14.5 ft-lb.) as compared to the three (3) remaining bars (21-25 ft. lb.). A subsequent metallographic analysis of this specimen showed a microstructure similar to Figure 6. Therefore, the apparent transformation problem was observed in both austenitizing procedures (2 vendors) and resulted in insufficient mechanical properties.

Forging No. 6006 displayed acceptable properties with the exception of high yield strength. Once more this discrepancy is not serious and can be corrected without difficulty.

Finally, two forgings, No. E305-3 and No. 6014, were quenched using a horizontal spray technique. This data is summarized in Table 3 and plotted in Figures 9 and 10. The 105mm M68 Forging (No. E305-3) displayed relatively high yield strengths with the exception of one value (151 ksi) in Disc MM. Correspondingly, the Charpy impact values tended to be low. Again, this condition appears to be related to the transformation characteristics of this material. The 155mm M185 forging

exhibited acceptable Charpy impact in spite of several values of yield strength in excess of 180 ksi.

In summarizing the results of this short-time austenitizing experiment, it is noteworthy that the mechanical properties, both tensile and Charpy impact strength, were generally acceptable. The exceptions or discrepancies were usually attributable to one specimen in a particular disc. This condition is associated with an incomplete transformation to austenite as well as experimental error and material variation. Although the transformation issue appeared occasionally and specimens with acceptable mechanical properties exhibited the typical tempered martensitic microstructure of gun steel, this reluctance to "solutionize" must be considered a potential problem. It is likely that chemical segregation, especially carbon[8], contributed to this problem. Therefore, it is necessary to conduct a more intensive evaluation of a particular product or component, considering material variation as well as the heat treatment parameters, in order to confidently establish the desired property levels.

Consequently, this data demonstrates that acceptable mechanical properties can be attained in full size gun tube forgings through shortened austenitizing cycles. However, the shortened cycles must be established for a particular component with consideration for material variation and the processing variables peculiar to each heat treatment operation. Presently, the conventional heat treatment processes of gun tube vendors take approximately 70 hours (furnace time) for a 105mm M68. This furnace time was reduced to approximately 12-20 hours in the current study. Considering the present and future costs of firing heat treatment furnaces and the potential increases in production capacity, due to a shortened cycle, this reduction in processing time can be highly significant.

Conclusions:

The results of this program demonstrate that reduced austenitizing times can yield acceptable mechanical properties in gun tube forgings. Although some discrepancies in the required properties were observed, they were primarily due to insufficient tempering (high yield strength). This condition can be corrected by adjusting the tempering temperature until the desired hardness level is obtained.

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8. P.A. Thornton and V. J. Colangelo, Met. Trans. 1976, Vol. 7B, pp 425-433.

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The discrepancies consisting of low yield strength ($<$ 160 ksi) accompanied by low Charpy impact ($<$ 15 ft-lb) were associated with incomplete transformation during the austenitizing cycle. This problem is related to both material inhomogeneity and variation in the heat treat parameters and must be considered on an individual component basis.

Additionally, the forgings treated by the horizontal spray quench method (No. E305-3 and No. 6014) demonstrated that acceptable mechanical properties could be achieved by this cooling technique. This is especially evident in the 155mm M185 forging (No. 6014) where all Charpy impact values exceeded the 15 ft-lb. minimum requirement.

APPENDICIES

APPENDIX I

AUSTENITIZATION TREATMENT
FORGINGS NO. 6047, 6006

TIME	TEMPERATURE (°F) #6047	#6006
0950	Tubes charged-Furnace 1200°F	
1030	840	820
1045	990	960
1100	1050	1020
1115	1120	1100
1130	1140	1120
1145	1150	1130
1200	1165	1150
1230*	1210	1210
1245	1300	1300
1300	1360	1360
1315	1440	1420
1330	1490	1480
1345	1510	1510
1400	1525	1520
1415	1545 Quench	1535
1430	-	1505
1445	-	1525 Quench

*Furnace control raised to 1550°F.

APPENDIX II

MECHANICAL PROPERTY DATA

105mm M68 No. 6048

Code	0.1% YS(ksi)	UTS(ksi)	%EL	%RA	-40° CVN(ft-lb)
48M1	180	200	15.0	41.6	16.5
M2	180	200	12.1	35.0	16.5
M3	182	200	12.8	36.3	17.0
M4	180	200	12.8	36.3	17.0
48MM1	174	195	14.3	41.2	20.0
MM2	175	196	15.0	42.8	20.0
MM3	174	196	14.3	41.6	18.5
MM4	174	195	10.0	27.5	18.5
48BB1	176	196	14.3	40.7	17.0
BB2	176	196	12.8	27.1	20.0
BB3	174	196	12.1	42.4	18.5
BB4	173	196	12.8	39.8	17.0
48B1	173	195	12.8	40.3	19.0
B2	174	195	12.8	31.8	18.5
B3	174	195	12.8	39.8	20.0
B4	174	195	13.6	39.8	18.0

105mm M68 No. 6043

Code	0.1% YS(ksi)	UTS(ksi)	%EL	%RA	-40° CVN(ft-lb)
43M1	186	204	9.3	22.2	14.0
M2	186	204	10.0	24.2	16.0
M3	187	204	12.8	32.2	15.0
M4	184	202	11.1	29.9	13.0
43MM1	182	199	12.1	36.3	16.0
MM2	181	199	12.1	36.3	16.0
MM3	180	198	12.1	32.7	17.0
MM4	182	199	11.5	29.0	18.0
43BB1	178	197	15.0	48.3	18.0
BB2	181	198	15.0	45.8	18.0
BB3	180	197	14.3	47.4	19.0
BB4	179	197	14.3	49.0	17.5

APPENDIX II

MECHANICAL PROPERTY DATA

(Continued)

Code	0.1% YS(ksi)	UTS(ksi)	%EL	%RA	-40°CVN(ft-lb)
105mm M68 No. 6043 (Continued)					
43B1	178	197	12.1	37.7	18.5
B2	180	197	15.0	47.0	19.0
B3	Tensile specimen lost				
B4	178	197	14.3	46.6	19.5
155mm M185 No. 6004					
04M1	191	207	12.8	39.4	14.0
M2	189	209	12.8	31.8	14.0
M3	189	208	8.6	15.6	14.0
M4	190	208	12.1	36.8	16.5
04MM1	181	202	13.6	38.5	18.0
MM2	182	202	11.1	23.7	17.0
MM3	183	202	12.8	36.3	18.5
MM4	183	202	7.2	5.4	18.0
04BB1	184	204	13.6	42.0	16.0
BB2	182	204	9.3	18.7	17.0
BB3	189	204	11.1	24.6	17.0
BB4	180	204	11.1	24.6	16.5
05B1	183	202	12.8	33.2	19.5
B2	180	200	12.8	37.7	18.5
B3	184	202	12.8	37.7	19.5
B4	181	202	11.5	31.8	19.0
155mm M185 No. 6007					
07M1	153	185	13.6	47.4	15.0
M2	159	188	11.1	26.6	13.0
M3	175	194	11.5	27.5	12.5
M4	154	185	15.0	44.1	13.5

APPENDIX II

MECHANICAL PROPERTY DATA

(Continued)

155mm M185 No. 6007 (Continued)

Code	0.1% YS(ksi)	UTS(ksi)	%EL	%RA	-40°CVN(ft-lb)
07MM1	177	196	15.0	45.4	22.0
MM2	176	196	14.3	42.0	21.0
MM3	176	195	13.6	39.4	23.0
MM4	177	196	15.0	47.8	22.5
07BB1	174	195	13.6	44.9	21.0
BB2	177	197	15.7	49.4	21.0
BB3	176	196	15.0	42.4	21.5
BB4	177	197	14.3	37.7	21.0
07B1	177	196	15.0	49.4	21.0
B2	175	197	12.8	35.8	20.0
B3	178	197	15.0	47.0	21.0
B4	177	197	15.0	45.4	20.0

105mm M68 No. 6047

Code	0.1% YS(ksi)	UTS(ksi)	%EL	%RA	-40°CVN(ft-lb)
47M1	182	199	11.5	35.8	19.5
M2	182	198	15.0	47.0	18.0
M3	182	199	15.7	48.3	17.0
M4	182	198	15.0	42.0	16.5
47MM1	180	198	9.3	17.7	17.5
MM2	182	200	15.0	46.2	19.0
MM3	180	199	15.0	39.4	16.5
MM4	180	196	9.3	18.7	18.5
47BB1	166	182	15.7	45.8	25.0
BB2	169	185	16.4	51.0	26.0
BB3	155	174	*	47.8	21.0
BB4	138	167	15.7	48.6	14.5
47B1	176	197	15.0	49.8	17.5
B2	177	197	15.7	47.0	16.0
B3	176	196	15.7	49.0	17.5
B4	176	197	12.8	38.5	16.0

* Outside gauge mark

APPENDIX II
MECHANICAL PROPERTY DATA
(Continued)

155mm M185 No. 6006

Code	0.1% YS(ksi)	UTS(ksi)	%EL	%RA	-40°CVN(ft-lb)
06M1	182	200	12.8	38.5	19.0
M2	182	200	14.3	39.8	17.5
M3	182	200	15.0	44.9	19.5
M4	182	200	11.5	28.0	20.0
06MM1	182	200	12.1	35.0	19.0
MM2	182	201	11.5	29.5	19.0
MM3	183	201	14.3	44.1	19.0
MM4	182	201	11.5	35.8	19.0
06BB1	177	197	13.6	34.0	19.5
BB2	176	195	15.0	44.9	21.5
BB3	178	197	13.6	42.4	22.5
BB4	176	195	14.3	44.9	19.0
06B1	185	204	12.8	36.8	16.5
B2	183	203	14.3	44.9	17.5
B3	186	204	15.0	42.4	15.0
B4	184	204	13.6	37.2	16.5

105mm M68 No. E305-3

Code	0.1% YS(ksi)	UTS(ksi)	%EL	%RA	-40°CVN(ft-lb)
53M1	175	196	12.8	36.3	14.0
M2	175	197	12.8	30.8	12.0
M3	174	195	12.1	32.2	12.5
M4	177	198	11.5	35.0	13.0
53MM1	176	195	11.5	35.0	14.5
MM2	171	192	9.3	21.7	15.5
MM3	176	194	11.5	34.0	13.5
MM4	151	185	14.3	41.2	14.0
53BB1	177	196	12.1	31.8	15.0
BB2	177	196	12.1	36.8	15.0
BB3	179	196	12.8	37.7	15.0
BB4	179	196	13.6	36.8	15.5
53B1	175	193	12.8	36.3	15.0
B2	175	194	12.8	36.3	15.0
B3	174	194	11.5	23.7	15.5
B4	174	194	13.6	36.8	15.0

APPENDIX II
MECHANICAL PROPERTY DATA
(Continued)

155mm M185 No. 6014

Code	0.1% YS(ksi)	UTS(ksi)	%EL	%RA	-40°CVN(ft-lb)
14M1	177	199	13.6	40.7	19.0
M2	176	198	14.3	39.4	17.5
M3	176	199	14.3	42.8	18.0
M4	178	200	13.6	36.3	19.5
14MM1	178	197	14.3	42.8	23.0
MM2	177	197	12.8	32.2	18.5
MM3	181	197	12.1	30.4	20.0
MM4	182	199	14.3	45.4	20.0
14BB1	181	198	13.6	39.0	23.0
BB2	180	199	14.3	41.2	21.0
BB3	181	200	14.3	42.4	18.0
BB4	182	198	13.6	42.4	21.0
14B1	179	199	14.3	45.4	18.5
B2	180	199	14.3	41.2	17.5
B3	179	199	13.6	42.8	17.5
B4	181	200	13.6	43.6	19.5

TABLE I

MECHANICAL PROPERTY SUMMARY **

VERTICAL IMMERSION QUENCH

FORGING	Disc Code	Avg. .1% YS (ksi)	Avg. UTS (ksi)	Avg. % El	Avg. % RA	Avg. CVN (-40°F) ft-lb
	48M	181*	200	13.2	37.3	16.8
105mm M68	48MM	174	195	13.4	38.3	19.2
No. 6048	48BB	174	196	13.0	37.5	18.1
	48B	174	195	13.0	37.9	18.9
	43M	186*	203	10.8	27.1*	14.5*
105mm M68	43MM	181*	199	12.0	33.6	16.8
No. 6043	43BB	180*	198	14.6	47.6	18.1
	43B	179	197	13.8	43.8	19.5
	04M	190*	208	11.6	30.9*	14.6*
155mm M185	04MM	182*	202	11.2	26.0*	17.9
No. 6004	04BB	184*	204	11.3	27.5*	16.6
	04B	182*	202	12.5	35.1	19.1
	07M	160*	188	12.8	36.4	13.5*
155mm M185	07MM	176	195	14.5	43.6	22.1
No. 6007	07BB	176	196	14.6	43.6	21.0
	07B	177	197	14.4	44.4	20.5
Required:		160-180			25 Min.	15 Min.

*Individual tests within these discs did not meet required specifications.

** Average of four specimens per disc.

TABLE II

MECHANICAL PROPERTY SUMMARY **

HORIZONTAL IMMERSION QUENCH

FORGING	Disc Code	Avg. 0.1% YS (ksi)	Avg. UTS (psi)	Avg. % El	Avg. % RA	Avg. CVN(-40°F) (ft-lb)
105mm M68 No. 6047	47M	182*	198	14.3	43.3	17.8
	47MM	180*	198	12.1	30.5*	17.9
	47BB	157*	177	15.9	48.5	21.6*
	47B	176	197	14.8	46.1	16.8
155mm M185 No. 6006	06M	182*	200	13.4	37.8	19.0
	06MM	182*	201	12.3	36.1	19.0
	06BB	177	196	14.1	41.6	20.6
	06B	184*	204	13.9	40.3	16.4
Required:		160-180			25 Min.	15 Min.

*Individual tests within these discs did not meet required specifications.

** Average of four specimens per disc.

TABLE III

MECHANICAL PROPERTY SUMMARY **

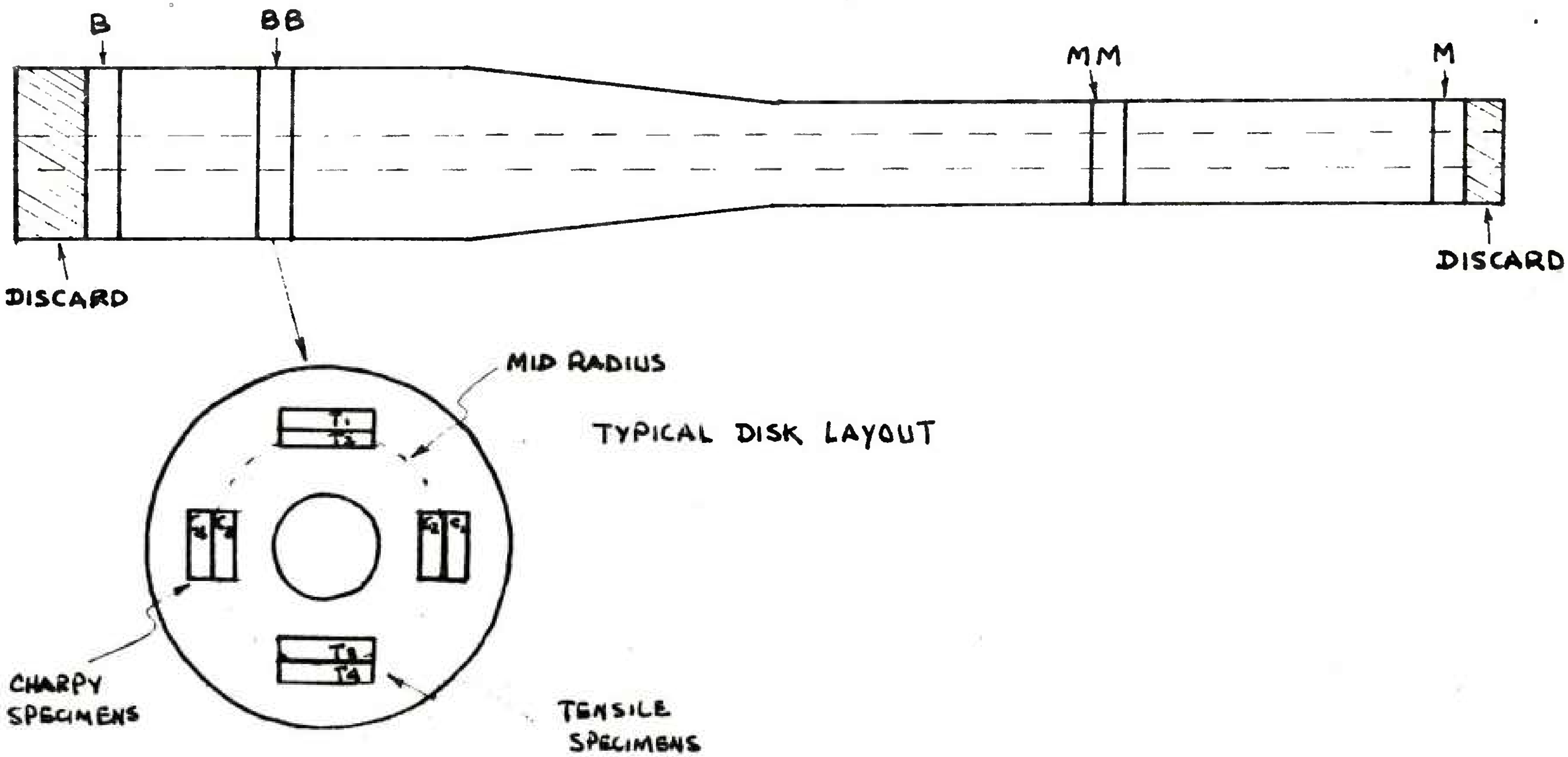
HORIZONTAL SPRAY QUENCH

FORGING	Disc Code	Avg. 0.1% YS (psi)	Avg. UTS (psi)	Avg. % El	Avg. % RA	Avg. CVN(-40°F) (ft-lb)
	53M	175	196	12.3	33.6	12.9*
105mm M68	53MM	168*	191	11.6	33.0	14.4*
No. E305-3	53BB	178	196	12.6	35.8	15.1
	53B	175	194	12.7	33.3*	15.1
	14M	177	199	14.0	39.8	18.5
155mm M185	14MM	179*	198	13.4	37.7	20.1
No. 6014	14BB	181*	199	14.0	41.2	20.8
	14B	179*	199	14.0	43.2	18.2
Required:		160-180			25 Min.	15 Min.

*Individual tests within these discs did not meet required specifications.

** Average of four specimens per disc.

Figure 1. Schematic of mechanical property sampling plan.



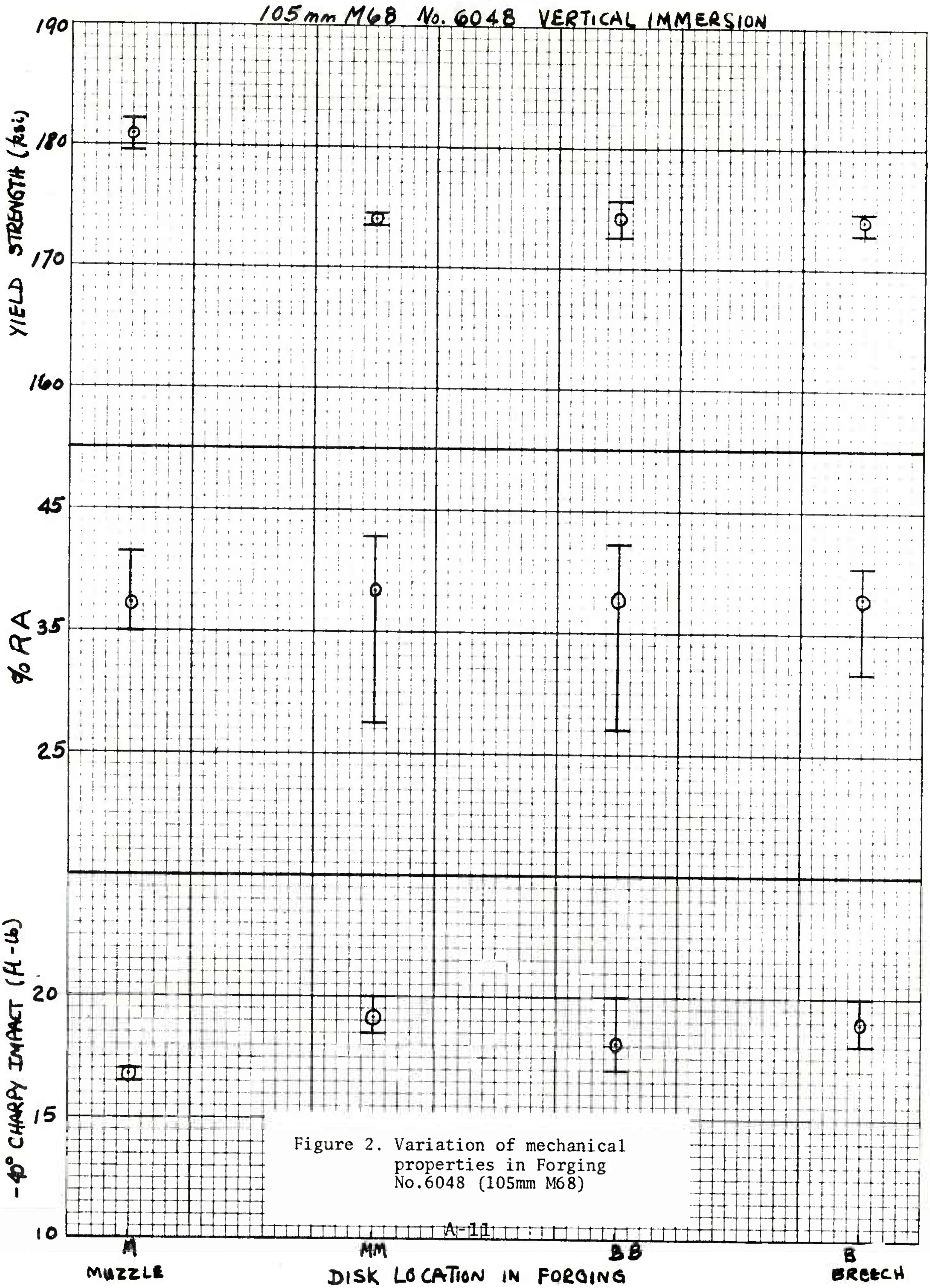


Figure 2. Variation of mechanical properties in Forging No.6048 (105mm M68)

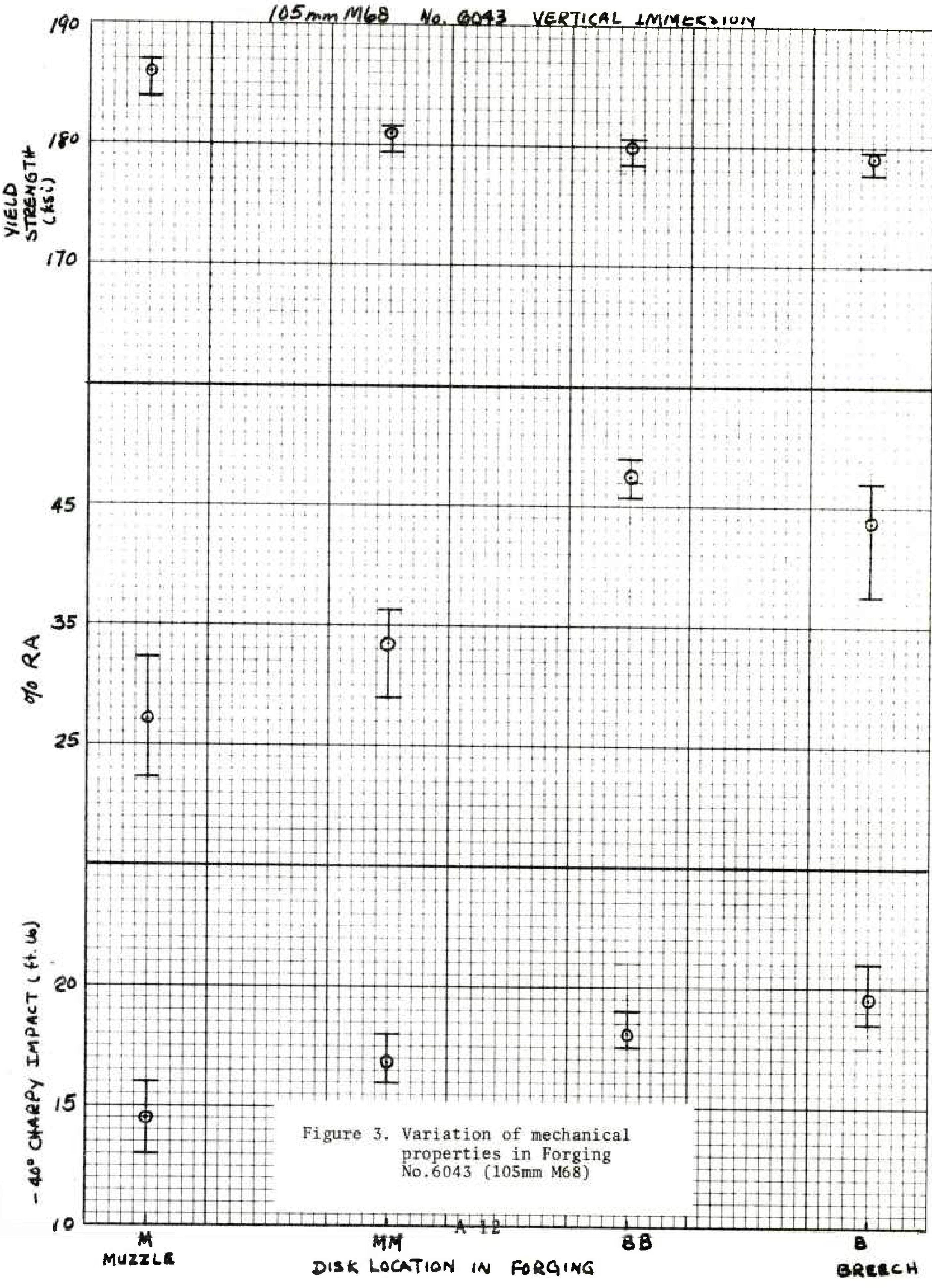


Figure 3. Variation of mechanical properties in Forging No.6043 (105mm M68)

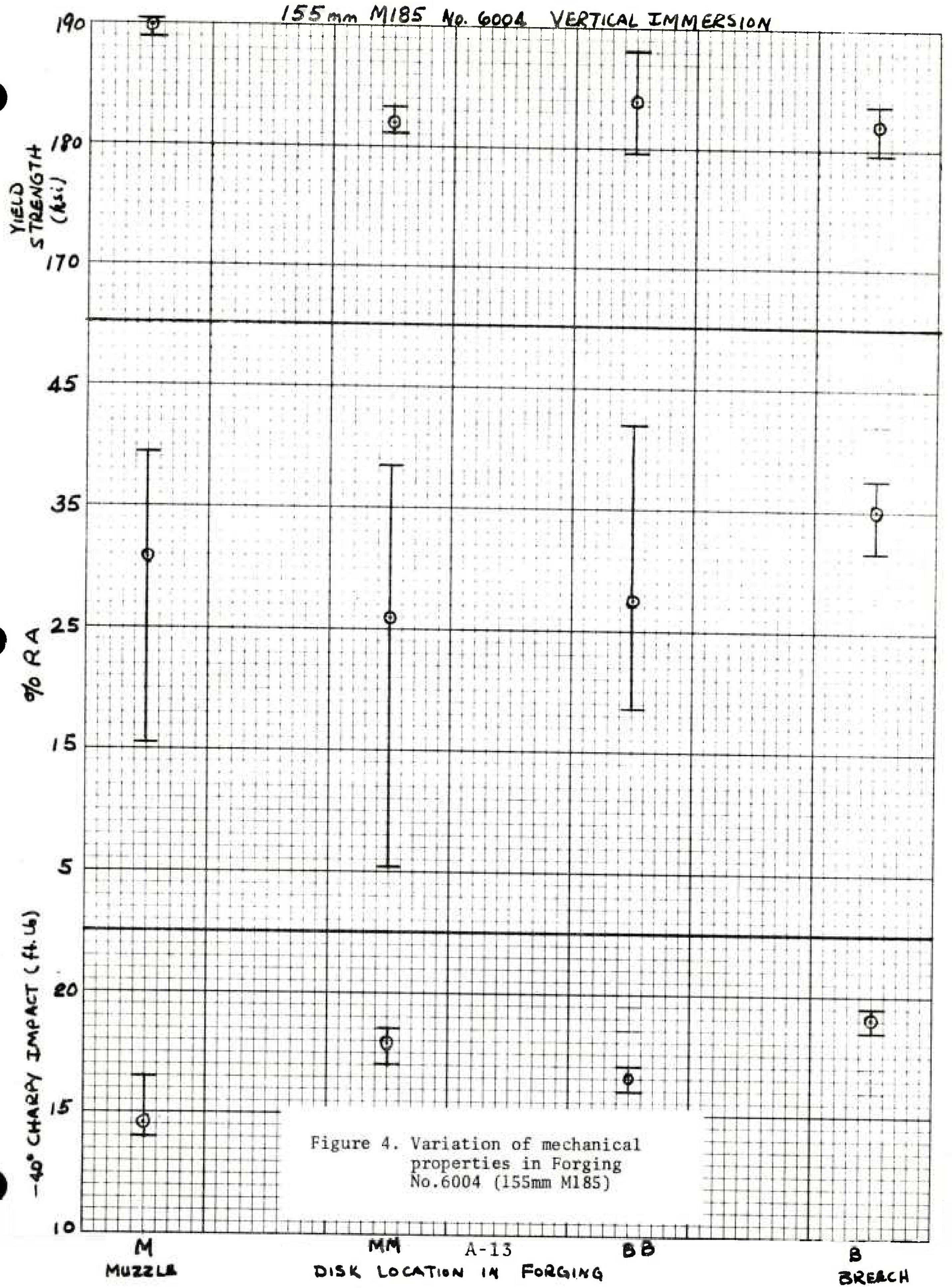


Figure 4. Variation of mechanical properties in Forging No.6004 (155mm M185)

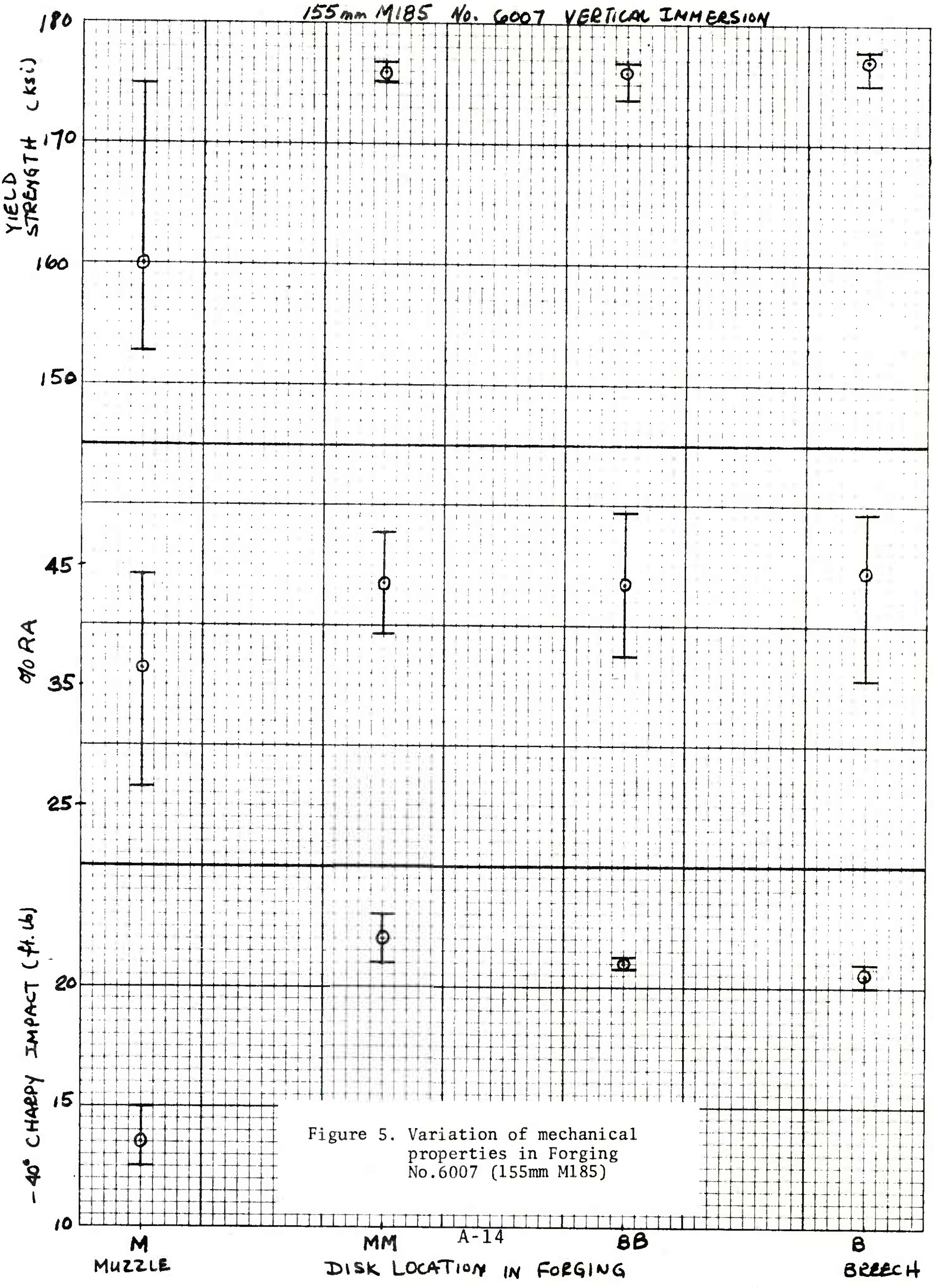


Figure 5. Variation of mechanical properties in Forging No.6007 (155mm M185)

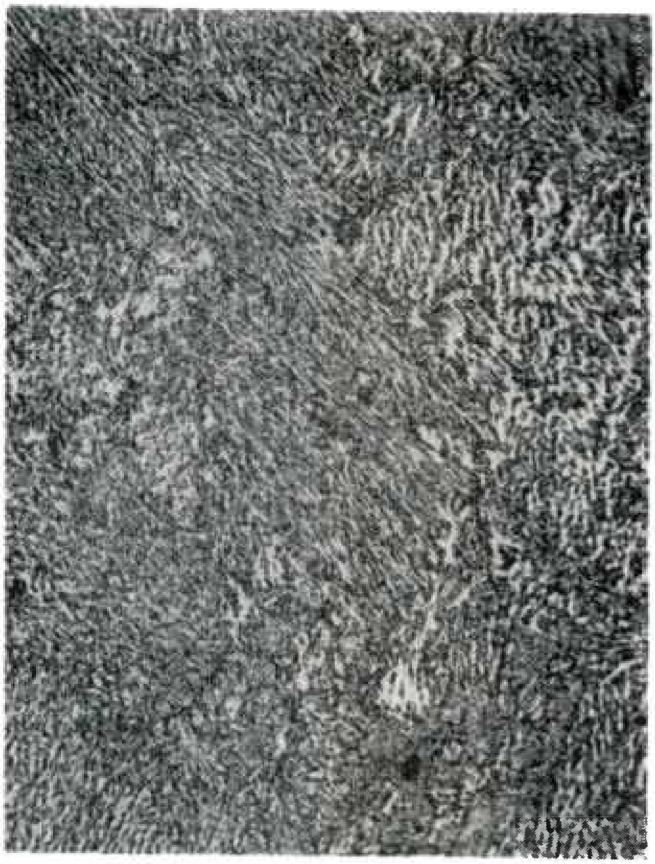


Figure 6. Photomicrograph of micro-
structure in Forging No.6007, showing
subtle laminar structure of Ferrite &
Carbide. 1000X. Picral + Hcl

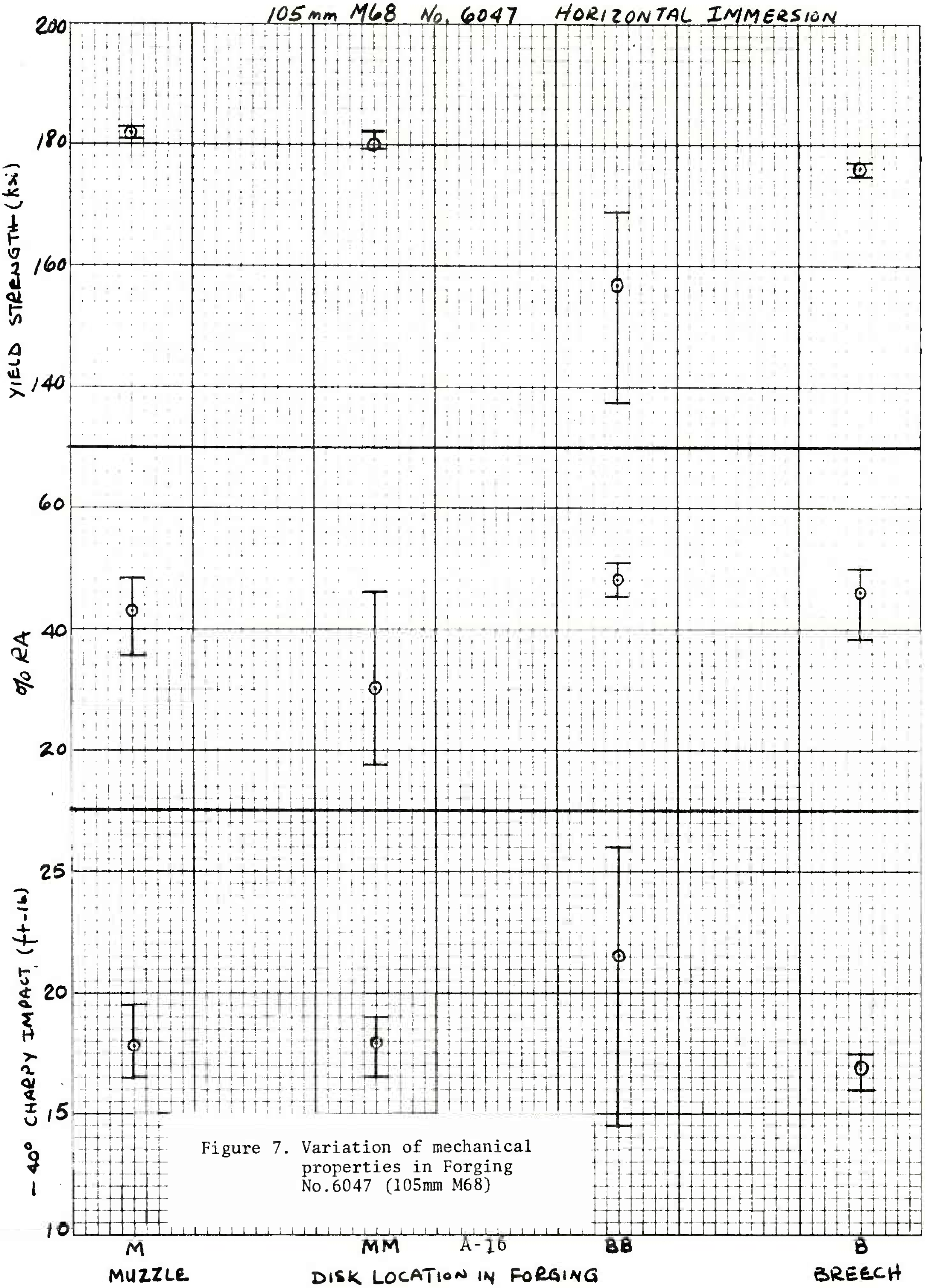


Figure 7. Variation of mechanical properties in Forging No.6047 (105mm M68)

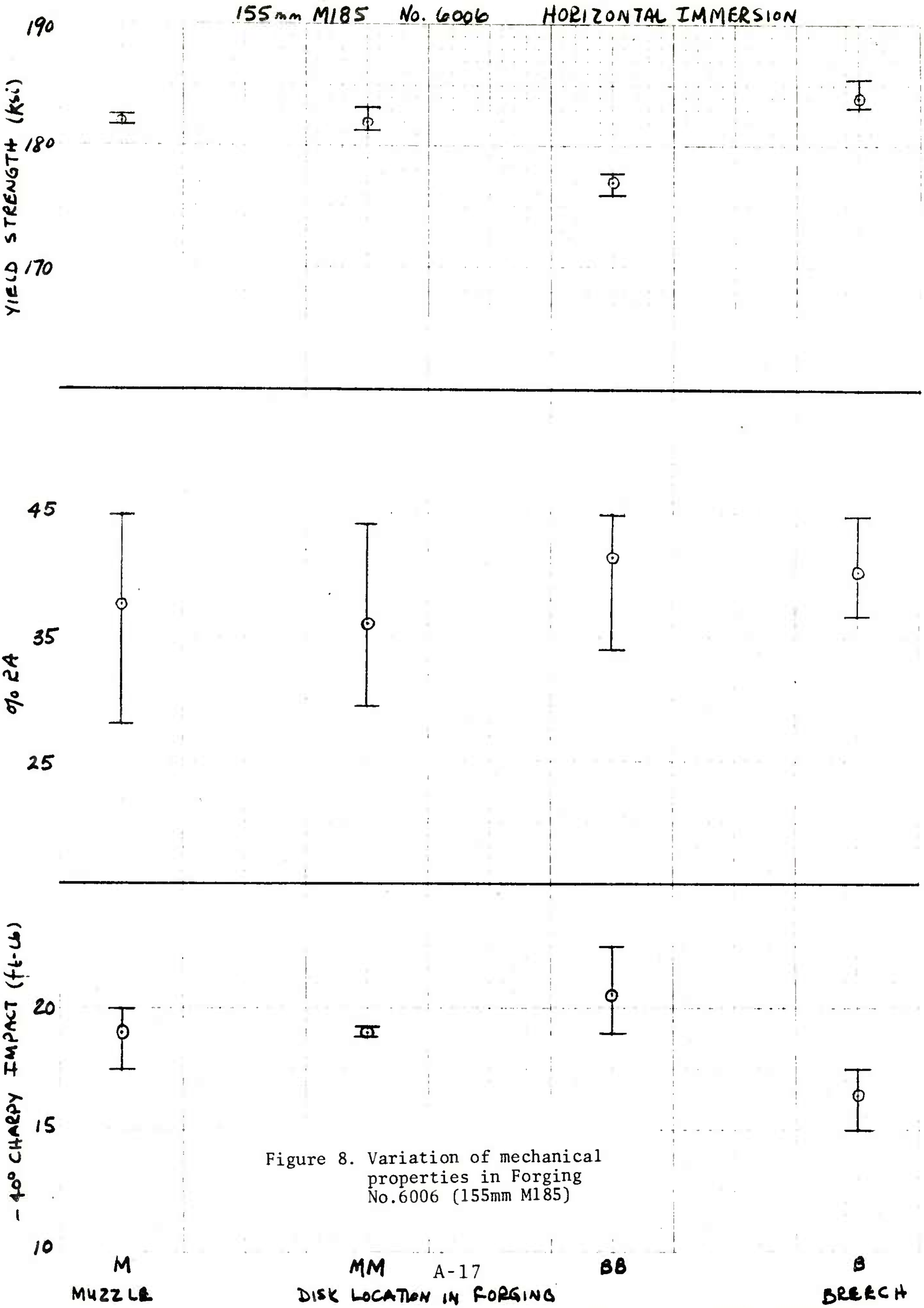


Figure 8. Variation of mechanical properties in Forging No.6006 (155mm M185)

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